LNG VAPOR HANDLING CONFIGURATIONS AND METHODS

This application claims the benefit of U.S. provisional patent applications with the serial numbers 60/517,298 (filed Nov. 3, 2003) and 60/525,416, (filed Nov. 25, 2003), both of which are incorporated by reference herein.

Field of the Invention

The field of the invention is LNG processing, especially as it relates to LNG vapor handling during LNG ship unloading or transfer.

Background of The Invention

LNG ship unloading is in many cases a critical operation that requires efficient integration with a regasification operation. Typically, when LNG is unloaded from an LNG ship to a storage tank, LNG vapors are generated from the storage tank due to volumetric displacement, heat gain during LNG transfer and in the pumping system, storage tank boiloff, and flashing due to the pressure differential between the ship and the storage tank. In most cases, the vapors need to be recovered to avoid flaring and pressure buildup in the storage tank system.

In a typical LNG receiving terminal, a portion of the vapor is returned to the LNG ship, while the remaining vapor portion is compressed by a compressor for condensation in a vapor absorber that uses the refrigeration content from the LNG sendout. Therefore, vapor compression and vapor absorption systems generally require significant energy and operator attention, and particularly during transition from normal holding operation to ship unloading operation. Alternatively, vapor control can be implemented using a reciprocating pump in which the flow rate and vapor pressure control the proportion of cryogenic liquid and vapor supplied to the pump as described in U.S. Pat. No. 6,640,556 to Ursan et al. However, such configurations are often impractical and generally fail to eliminate the need for vapor recompression in LNG receiving terminals.

Alternatively, or additionally, a turboexpander-driven compressor may be employed as described in U.S. Pat. No. 6,460,350 to Johnson et al. Here the energy requirement for vapor recompression is typically provided by expansion of a compressed gas from another source. However, where a compressed gas is not

readily available from another process, generation of the compressed gas is energy intensive and uneconomical.

In other known systems, methane product vapor is compressed and condensed against an incoming LNG stream as described in published U.S. patent application to Prim with the publication number 2003/0158458. While Prim's system increases the energy efficiency as compared to other systems, various disadvantages nevertheless remain. For example, vapor handling in Prim's system is typically limited to plants in which production of a methane rich stream is desired.

In yet another system, as described in US patent 6,745,576, a plurality of mixers, collectors, pumps, and compressors are used for re-liquefying boil-off gas in an LNG stream. In this system, the atmospheric boil-off vapor is compressed to a higher pressure using a vapor compressor such that the boil-off vapor can be condensed. While such a system typically provides improvements of control and mixing devices in a vapor condensation system, it nevertheless inherits most of the disadvantages of known configurations as shown in **Prior Art Figure 1**.

Moreover, the composition and heating values of most imported LNG varies dramatically and will generally depend on the particular source. While LNG with heavier contents or higher heating value can be produced at lower costs at the source, they are often not suitable for the North American market. For example, natural gas for the Californian market must meet a heating value specification of 950 Btu/SCF-1150 Btu/SCF, and must meet composition limitations on its C_2 and C_3+ components. Especially where LNG is used as transportation fuel, the C_2+ content must be further reduced to avoid high combustion temperature and reduce greenhouse emissions. **Table 1** depicts composition requirements in comparison to a typical imported LNG supply. Thus, it would also be desirable to configure an LNG receiving terminal with the capability to accommodate to varying LNG compositions.

Unfortunately, most of the currently known processes and configurations for LNG ship unloading and regasification fail to address various difficulties. Among other things, many of the known processes require vapor compression and absorption that are energy inefficient. Still further all or almost all of the known processes fail to economically remove heavy hydrocarbons from LNG to meet stringent environmental

standards. Thus, there is still a need to provide improved configurations and methods for gas processing in LNG unloading and regasification terminals.

Summary of the Invention

The present invention is directed to various configurations and methods for an LNG plant (most preferably to an LNG regasification terminal) comprising an LNG storage vessel and fractionator configured to receive liquefied natural gas from an LNG carrier vessel and to provide LNG liquid and LNG vapor. A fractionator is fluidly coupled to the storage vessel and receives a fractionator feed, wherein the fractionator produces C_2 and lighter components as an overhead product and C_3 and heavier components as a bottom product. In preferred configurations, the refrigeration content of the liquefied natural gas liquid is used to condense the C_2 and lighter components, while the C_3 and heavier components are combined with the LNG vapor to absorb the LNG vapor to thereby form the fractionator feed.

In further preferred aspects of the inventive subject matter, contemplated plants include a first heat exchanger to cool the fractionator feed using the liquefied natural gas liquid as a refrigerant, and/or a second heat exchanger that heats the fractionator feed using the stream of C_3 and heavier components from the fractionator as a heat source. In still further contemplated plants, a portion of the LNG vapor from the storage vessel is routed to a second LNG storage vessel (LNG carrier), or the second LNG storage vessel may produce a vapor that is rerouted back to the second LNG storage vessel during ship unloading.

Preferred fractionators are typically configured to provide the condensed C_2 and lighter components to the liquefied natural gas liquid. Alternatively, or additionally, the fractionator may also be configured to receive a portion of the liquefied natural gas liquid as fractionator feed (after the liquefied natural gas liquid has provided refrigeration for condensation of the C_2 and lighter components).

Moreover, in yet further contemplated aspects, the fractionator may further be configured to provide liquefied petroleum gas (LPG) as a bottom product. In such configurations, the fractionator may be configured to receive another portion of the liquefied natural gas liquid as condensation refrigerant after the liquefied natural gas

liquid provided refrigeration for condensation of the C_2 and lighter components to enhance condensation.

Thus, contemplated methods include methods of handling liquefied natural gas vapor in which a liquefied natural gas storage vessel provides LNG liquid and LNG vapor. In another step, the LNG vapor is combined with a stream of C_3 and heavier components to thereby absorb the LNG vapor and to thereby form a combined product. In yet another step, the combined product is separated in a fractionator into the stream of C_3 and heavier components and a stream of C_2 and lighter components, and the stream of C_2 and lighter components is condensed using the refrigeration content of the LNG liquid.

Various objects, features, aspects and advantages of the present invention will become more apparent from the accompanying drawings and detailed description of preferred embodiments of the invention.

Brief Description of the Drawing

Figure 1 is a Prior Art schematic of an LNG unloading configuration.

Figure 2 is a schematic of an exemplary LNG unloading configuration with an external vapor return line.

Figure 3 is a schematic of an exemplary LNG unloading configuration without an external vapor return line.

Figure 4 is a schematic of an exemplary LNG unloading configuration with an external vapor return line and LPG production capability.

Detailed Description

The present invention is generally directed to configurations and methods of LNG vapor handling in which the vapor (in most cases predominantly comprising N_2, C_1 and C_2) is combined with a heavier hydrocarbon (in most cases predominantly comprising C_3, C_4 and heavier components) to form a hydrocarbon mixture having a condensation temperature that is higher than that of the LNG vapor. The so generated mixture is subsequently condensed using the refrigeration content of the LNG liquid and the liquid is pumped to a higher pressure. The pressurized mixture is then heated,

and (C_2 and lighter) vapor is separated from the mixture in a fractionator at elevated pressure. The fractionator overhead vapor is condensed using the refrigeration content of the LNG liquid, while the heavier hydrocarbon produced by the fractionator is recycled to the point of combination with LNG vapor.

In a particularly preferred aspect of the inventive subject matter, contemplated configurations and methods are realized in LNG ship unloading and/or regasification operation in both on-shore and/or off-shore LNG regasification terminals. It should be especially appreciated that in such configurations the need for a vapor compressor for condensation of the vapors is eliminated by mixing the vapor with a component that increases the boiling point of the mixture to a degree such that at least a portion of the mixture can be condensed using the refrigeration content of the LNG liquid.

Preferably, the heavier hydrocarbon comprises C_3 and heavier hydrocarbon components that may be added from an external source, or even more preferably, that are extracted from the LNG that is unloaded. Thus, and at least in some aspects of the inventive subject matter, contemplated configurations include a fractionation system comprising heat exchangers, pumps and fractionators that is configured to utilize the refrigeration released in the regasification process for the separation of LNG into a leaner natural gas and a LPG (Liquefied Petroleum Gas) product. Further contemplated configurations and methods for regasification of LNG that may be used in conjunction with the teachings presented herein are described in our copending International patent application number with the serial number PCT/US03/25372, filed August 13, 2003, and which is incorporated herein by reference.

Configurations and methods of the inventive subject matter are contrasted with a conventional LNG carrier unloading and regasification terminal schematically depicted in **Prior Art Figure 1**. Here, LNG typically at -255°F to -260°F is unloaded from a LNG carrier ship 50 via unloading arm 51, the transfer line 1 into storage tank 52, typically at a flow rate of 40,000 GPM to 60,000 GPM. The unloading operation generally lasts for about 12 to 16 hours, and during this period, about 40 MMscfd of vapor is generated from the storage tank, as a result from the enthalpy gain (either by the ship pumps or heat gain from the surroundings) during the transfer operation, the displacement vapor from the storage tanks, and the liquid flashing from the pressure difference between the ship and the storage tank.

An LNG carrier ship typically operates at a pressure slightly less than that of the storage tank, and typically, the LNG ship operates at 16.2 psia to 16.7 psia while the storage tank operates at 16.5 psia to 17.2 psia. The vapor from the storage tank, stream 2, is split into two portions, stream 3 and stream 4. Stream 3 typically at a flow rate of 20 MMscfd is returned to the LNG ship via a vapor return line and return arm 54 for replenishing the displaced volume from ship unloading. Stream 4, typically at a flow rate of 20 MMscfd, is compressed by compressor 55 to about 80 psia to 115 psia and fed as stream 5 to the vapor absorber 58 where the vapor is de-superheated, condensed and absorbed from stream 9 by the sendout LNG. The power consumption by compressor 55 is typically 1,000 HP to 2,000 HP, depending on the vapor flow rate and compressor discharge pressure.

LNG from the storage tank 52 is pumped by the in-tank primary pumps 53 to about 115 to 150 psia forming stream 6, at a typical sendout rate of 250 MMscfd to 1,200 MMscfd. Stream 6 is split into stream 7 and stream 8 using the respective control valves 56 and 57, as needed for controlling the vapor condensation process. Stream 7, a subcooled liquid at -255°F to -260°F, is routed to the absorber 58 to mix with the compressor discharge stream 5 using a heat transfer contacting device such as trays and packing. The operating pressures of the vapor absorber and the compressor are determined by the LNG sendout flow rate. A higher LNG sendout rate with a higher refrigeration content would lower the absorber pressure, and hence require a smaller compressor. However, the absorber design should also consider the normal holding operation when the vapor rate is lower, and the liquid rate must be reduced to a minimal.

The vapor absorber produces a bottom stream 9 typically at about -200°F to -220°F, which is then mixed with stream 8 forming streaming 10. Stream 10 is pumped by the secondary pump 59 to typically 1000 psig to 1500 psig forming stream 11 which is then heated in LNG vaporizers 60 to about 40°F to 60°F as needed to meet the pipeline specifications. The LNG vaporizers are typically open rack type exchangers using seawater, fuel-fired vaporizers, or vaporizers using a heat transfer fluid.

In contrast, the inventors discovered configurations and methods in which LNG ship unloading is operationally coupled to an LNG regasification/processing

plant and in which LNG vapor handling process and efficiency is significantly improved. Among other advantages, contemplated configurations and methods eliminate the need for vapor recompression and therefore substantially decrease capital and energy requirements. An exemplary configuration is depicted in **Figure 2** in which vapor absorption is carried out at storage tank overhead pressure using a heavy hydrocarbon liquid (*e.g.*, C_3 and heavier) for absorption, with the heavy hydrocarbon separated from LNG using a fractionator. The refrigeration content in the LNG is used for cooling in the absorption process by removing the heat of absorption and condensation as well as in supplying the reflux condensing duty in the fractionator. As the mixture of the vapors and the heavy hydrocarbon liquid condenses at significantly higher temperature, it should be recognized that a compressor and vapor absorber as depicted in prior art Figure 1 are no longer required. Instead, these elements are replaced by a low pressure condenser exchanger and pumping system, which are installed and operated at significantly reduced cost.

Viewed from another perspective, it should be recognized that in contemplated configurations the composition of the vapors from the storage tank is modified by mixing these vapors with a subcooled heavy hydrocarbon stream (the addition of heavy hydrocarbons increases the boiling point temperature, and therefore allows condensation of the mixture with LNG). This mixture is pumped to and separated in a downstream fractionator for recovery and/or recycling of the heavier hydrocarbons.

With further reference to Figure 2, LNG liquid as stream 1 is provided from the LNG carrier ship 50 to the storage tank 52 via unloading line 51. Vapor stream 2 from storage tank 52 is split into stream 3 and stream 4. Stream 3, typically at a flow rate of 20 MMscfd, is returned to the LNG carrier ship 50 via a vapor return line and return arm 54 for replenishing the displaced volume from ship unloading. Stream 4, typically at a flow rate of 20 MMscfd, is mixed with the heavy hydrocarbon stream 16 (typically containing C_3, C_4, and heavier hydrocarbons). To raise the boiling point of the mixture, typically about 200 GPM to 500 GPM heavy hydrocarbons is required from the downstream fractionation system. Where the heavy hydrocarbon fraction is not available from the LNG source for raising the boiling temperature and condensation of the mixture stream 17, the system may be charged with the heavy hydrocarbons from an external source. The combined stream 17 is cooled and

condensed in exchanger 61 to stream 18 using the refrigeration content from the LNG stream 6 (provided from tank 52 via primary pump 53) typically at -240°F to -255°F.

It should be appreciated that the heavy hydrocarbon composition and flow rate of the heavy hydrocarbon fraction can be controlled in the fractionator as necessary to absorb the vapors from the storage tank during the ship unloading and the normal holding operation. For example, a LNG vapor rich in the lighter components such as N_2 and C_1, will proportionally require more LNG flow and heavier components for absorption and condensation. Therefore, flow rates of less than 200 gpm and higher than 500 gpm are also deemed suitable. A person of ordinary skill in the art will readily determine suitable flow rates, which will predominantly depend on the amount of vapor and the composition of the heavy hydrocarbon.

Moreover, it should be recognized that the components selection of the hydrocarbon is not critical so long as the hydrocarbon will increase the boiling point temperature to a degree sufficient to allow condensation of the combined stream using the refrigeration content of the LNG liquid. Therefore, suitable components for admixture with the vapor stream especially include propane, butane, and higher hydrocarbons.

In exchanger 61, stream 6 is heated from -255°F to about -240°F and supplies the necessary cooling for condensing the combined stream 17. The condensate stream 18 is then pumped by pump 62 to about 120 psia to 170 psia forming stream 19. Prior to feeding stream 19 to the fractionator 64, the pressurized stream 19 is heated to about -10°F to 150°F and partially vaporized in exchanger 63 by heat exchange with the bottom liquid 21 from the fractionator 64 to thereby form heated stream 20. The fractionator 64, typically operating at about 100 psia to 150 psia, separates the heated combined stream 20 into an overhead liquid stream 22 (containing mostly C_2 and lighter components) and bottom liquid stream 21 (containing mostly C_3 and heavier components). The fractionator is refluxed using the refrigeration content from LNG stream 7 in an overhead condenser 65 (which can be separate or integral to fractionator 64). Where desirable, overhead condenser 65 can also be located external to the fractionator, and the liquid stream 22 can be separated in an external located drum (not shown). The fractionator is preferably reboiled using an external heat source with a fired reboiler, steam, or other heat source.

The overhead stream 22, which is depleted of the heavy hydrocarbons (C_3 and heavier) is mixed with the LNG stream 23 forming stream 10. The combined sendout stream 10 is then pumped by the secondary pump 59 to typically 1000 psig to 1500 psig forming stream 11, which is then heated in LNG vaporizers 60 to about 40°F to 60°F as needed to meet the pipeline specifications. The LNG vaporizers are typically open rack type exchangers using seawater, fuel-fired vaporizers, or vaporizers using a heat transfer fluid.

In another aspect of contemplated configurations, as shown in **Figure 3**, vapor from the storage tank 52 is not returned to the LNG carrier ship 50. Consequently, no vapor return line and vapor return arm are needed. Instead, the vapor required by the ship for maintaining volumetric balance is generated with a small vaporizer proximal to or even on the ship. Here, a small stream 30 of LNG liquid is vaporized in the heat exchanger 67 to produce vapor stream 3 to achieve a vapor flow of about 20 MMscfd to replenish the displaced volume from the ship. The heat source 31 to the vaporizer 67 can be seawater or ambient air. Such configurations are thought to result in further significant cost savings in the terminal design, particularly in a facility where there is a relatively large distance between the ship 50 and the storage tank 52. Consequently, the entire vapor stream 2 from the tank is combined with heavy hydrocarbon stream 16, absorbed and condensed with LNG stream 6 under similar conditions as described above. In such configurations, the flow rate of stream 16 is increased correspondingly to about 400 GPM to 1,200 GPM, as needed for the absorption of the higher LNG vapor flow. With respect to the remaining components and numerals in Figure 3, the same considerations and designations as provided for Figure 2 above apply.

In yet another preferred aspect of the inventive subject matter, and especially where it is desired to extract LPG from the crude LNG, or to otherwise modify the chemical composition of the LNG (*e.g.*, to meet environmental regulations or pipeline specifications), additional cooling may be provided to the fractionator as depicted in exemplary configuration of **Figure 4**. In such configurations, the overhead condenser 65 of fractionator 64 includes a second refrigeration coil 66 integral to the column that uses the high pressure LNG to provide additional cooling as needed for higher reflux duty required for LPG production. Alternatively, heat exchanger coil 66 and coil 65 can be located external to the column in separate heat exchangers, and liquid stream

22 can be separated in an external drum. Here, the LNG stream 26 exiting the condenser coil 65 at about -220°F to -240°F is split into two portions; stream 23 and stream 24. It should be recognized that the exact amount of stream 24 may vary considerably and will predominantly depend on the quality and quantity of the LPG that is desired. Therefore, stream 24 may be between 0 to 100% of stream 26 (increasing stream 24 increases LPG production). With increasing LPG production, it should be recognized that the distillate becomes leaner in composition. Among other desirable effects, a leaner LNG with lower heating value may be more desirable to meet environmental regulations.

Stream 24 is preferably fed to about the mid section of the fractionator that produces a bottom LPG stream 28, and an overhead distillate liquid stream 22 that is depleted of the heavy hydrocarbons. The distillate stream 22 is then mixed with the LNG stream 23 forming stream 10 typically at -220°F to -230°F that is further pumped by the secondary pump 59 to about 1,000 psig to 1,400 psig forming stream 11. The high pressure LNG stream is heat exchanged with the overhead vapor in reflux condenser coil 66 forming stream 27, typically at about -180°F to -200°F. Stream 27 is further heated in vaporizer 60 to meet the pipeline gas requirement. The bottom stream 28 is typically split into two portions; stream 25 and stream 21. Stream 21 is recycled back to exchanger 63 prior to its use for vapor absorption, and remaining stream 25 can be sold as the LPG product. With respect to the remaining components and numerals in Figure 4, the same considerations and designations as provided for Figure 2 above apply.

Based on the above exemplary configurations, the inventors contemplate a plant that includes an LNG storage vessel that receives LNG (preferably from a second LNG storage vessel, and most preferably from a LNG carrier ship) and that provide LNG liquid and LNG vapor. A fractionator produces a stream of C_2 and lighter components and a stream of C_3 and heavier components from a fractionator feed, wherein the refrigeration content of the liquefied natural gas liquid condenses the C_2 and lighter components, and wherein the C_3 and heavier components absorb the liquefied natural gas vapor thereby forming the fractionator feed.

In especially preferred plant configurations, a first heat exchanger cools the fractionator feed using the liquefied natural gas liquid as a refrigerant to thereby

condense the mixture of the LNG vapor and the C_3 and heavier components, while a second heat exchanger heats the (preferably pressurized) fractionator feed using the stream of C_3 and heavier components from the fractionator as a heat source. In further preferred aspects, the separated and condensed C_2 and lighter components are combined with the LNG liquid (after the LNG liquid has been used as refrigerant).

Still further preferred configurations also include those in which the fractionator receives a portion of the liquefied natural gas liquid as fractionator feed (preferably after the liquefied natural gas liquid has provided refrigeration for condensation of the C_2 and lighter components), and in which the fractionator is configured to provide liquefied petroleum gas (LPG) as a bottom product. In such configurations, it is further preferred that another portion of the LNG liquid is used as condensation refrigerant after the liquefied natural gas liquid has provided refrigeration for condensation of the C_2 and lighter components.

Consequently, the inventors contemplate a method of handling LNG vapor in which LNG liquid and LNG vapor are provided by a LNG storage vessel. In another step, the LNG vapor is combined with a stream of C_3 and heavier components to thereby absorb the liquefied natural gas vapor and to thereby form a combined product, and in yet another step, the combined product is separated in a fractionator into the stream of C_3 and heavier components and a stream of C_2 and lighter components. In still another step, the stream of C_2 and lighter components is condensed using refrigeration content of the liquefied natural gas liquid.

Thus, specific embodiments and applications of LNG vapor handling and regasification have been disclosed. It should be apparent, however, to those skilled in the art that many more modifications besides those already described are possible without departing from the inventive concepts herein. The inventive subject matter, therefore, is not to be restricted except in the spirit of the disclosure. Moreover, in interpreting the specification, all terms should be interpreted in the broadest possible manner consistent with the context. In particular, the terms "comprises" and "comprising" should be interpreted as referring to elements, components, or steps in a non-exclusive manner, indicating that the referenced elements, components, or steps may be present, or utilized, or combined with other elements, components, or steps that are not expressly referenced.